UNIFIED MODELS OF TURBULENCE AND NONLINEAR WAVE EVOLUTION IN THE EXTENDED SOLAR CORONA AND SOLAR WIND

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1. Required Information

Type of report	**Annual Progress Report**
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Name of the principal investigator ..	Dr. Steven R. Cranmer
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2. Scientific Accomplishments during the Report Period

The PI (Cranmer) and Co-I (A. van Ballegooijen) made significant progress toward the goal of building a "unified model" of the dominant physical processes responsible for the acceleration of the solar wind. The approach outlined in the original proposal comprised two complementary pieces: (1) to further investigate individual physical processes under realistic coronal and solar wind conditions, and (2) to extract the dominant physical effects from simulations and apply them to a one-dimensional and time-independent model of plasma heating and acceleration. The accomplishments in the report period are thus divided into these two categories:

1a. *Focused Study of Kinetic MHD Turbulence.* We have developed a model of magnetohydrodynamic (MHD) turbulence in the extended solar corona that contains the effects of collisionless dissipation and anisotropic particle heating. A turbulent cascade is one possible way of generating small-scale fluctuations (easy to dissipate/heat) from a pre-existing population of low-frequency Alfvén waves (difficult to dissipate/heat). We modeled the cascade as a combination of advection and diffusion in wavenumber space. The dominant spectral transfer occurs in the direction perpendicular to the background magnetic field. As expected from earlier models, this leads to a highly anisotropic fluctuation spectrum with a rapidly decaying tail in the parallel wavenumber direction. The wave power that decays to high enough frequencies to become ion cyclotron resonant depends on the relative strengths of advection and diffusion in the cascade. For the most realistic values of these parameters, though, there is insufficient power to heat protons and heavy ions. The dominant oblique waves undergo Landau damping, which implies strong parallel electron heating. We thus investigated the nonlinear evolution of the electron velocity distributions (VDFs) into parallel beams and discrete phase-space holes (similar to those seen in the terrestrial magnetosphere) which are an alternate means of heating protons via stochastic interactions similar to particle-particle collisions.

1b. *Focused Study of the Multi-Mode Detailed Balance Formalism.* The PI began to explore the feasibility of using the "weak turbulence," or detailed-balance theory of Tsytovich, Melrose, and others to encompass the relevant physics of the solar wind. This study did not go far, however, because if the "strong" MHD turbulence discussed above is a dominant player in the wind's acceleration region, this formalism is inherently not applicable to the corona. We will continue to study the various published approaches to the weak turbulence formalism—especially with an eye on ways to parameterize nonlinear wave reflection rates.

2. *Building the Unified Model Code Architecture.* We have begun developing the computational model of a time-steady open flux tube in the extended corona. The model will be "unified" in the sense that it will include (simultaneously for the first time) as many of the various proposed physical processes as possible, all on equal footing. To retain this generality, we have formulated the problem in two interconnected parts: a completely kinetic model for the particles, using the Monte Carlo approach, and a finite-difference approach for the self-consistent fluctuation spectra. The two codes are run sequentially and iteratively until complete consistency is achieved. The current version of the Monte Carlo code incorporates gravity, the zero-current electric field, magnetic mirroring, and collisions. The fluctuation code incorporates WKB wave action conservation and the cascade/dissipation processes discussed above. The codes are being run for various test problems with known solutions. Planned additions to the codes include prescriptions for nonlinear wave steepening, kinetic velocity-space diffusion, and multi-mode coupling (including reflection and refraction).

3. Comparison of Accomplishments with Proposed Goals

The proposal contained three specific objectives for "Year 1" that correspond to the three accomplishments presented above. The PI began to develop the unified model code, with detailed testing already underway. (The proposal stated that we may discard the assumption of bi-Maxwellian VDFs in favor of a more faithful representation of the VDFs in the weakly-collisional extended corona, and indeed we have done so with the use of the Monte Carlo approach.) The PI began the process of investigating the applicability of the detailed-balance formalism, but it may not be a feasible addition to the eventual unified model. (This possibility was anticipated in the proposal.) Finally, the PI and Co-I developed very successful simulations of MHD turbulent cascade in plasmas with coronal conditions.

4. Publications and Conference Presentations

The MHD turbulence model was presented at the December 2002 AGU Meeting in San Francisco, California, and submitted as a paper to the *Astrophysical Journal* in January 2003. Progress reports on the unified Monte Carlo model will be presented at the June 2003 AAS/SPD Meeting in Laurel, Maryland and the July 2003 IUGG/IAGA General Assembly in Sapporo, Japan.

As a separate activity (not covered by this grant), the PI also published a 65-page review paper (*Space Sci. Rev.*, 2002) on coronal holes and the high-speed solar wind that has helped to focus the PI and Co-I on the relevant physical processes to include in the unified models.

5. Statement of Work for the Next Report Period

The Work Plan for the following year (May 1, 2003 to April 30, 2004) is expected to follow closely the "Year 2" description in the original proposal. The PI will extend the unified model code by incorporating more physical processes, modeling more ions, and including the kinetic dissipation/growth of an arbitrary number of wave modes. The PI and Co-I will extend the MHD turbulence models by investigating both: (1) the effects of magnetic reconnection on ion heating, and (2) a more consistent model of electron phase-space hole growth and evolution. The results of the MHD turbulence and detailed-balance studies will be incorporated into the unified model code.

We thus request that NASA release the next year's award funds in the previously agreed-to amount of $62,116.